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**SYSTEMS ENGINEERING TECHNOLOGY P-44
FOR NETWORKS**

FINAL REPORT

Submitted to:

**COMPUTATIONAL SCIENCE AND
ENGINEERING RESEARCH CENTER**

HOWARD UNIVERSITY
2216 Sixth Street, N.W.
Washington, D.C. 20059

Submitted by:

SYSTEMS ENGINEERING DESIGN LABORATORY

VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY
Blacksburg, Virginia 24061

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FOREWORD

The following report summarizes research pursued within the Systems Engineering Design Laboratory at Virginia Polytechnic Institute and State University between May 16, 1993 and January 31, 1994. The project was proposed in cooperation with the Computational Science and Engineering Research Center at Howard University. Its purpose was to investigate emerging Systems Engineering tools and their applicability in analyzing the NASA Network Control Center (NCC) on the basis of metrics and measures.

1. OBJECTIVE(S) OF THE RESEARCH

The objectives of this research project are to:

- (1) Formulate additional performance measures which may be used to quantify, in an operational and practical manner, the performance of the Network Control Center (NCC) from the user's point of view.
- (2) Investigate and demonstrate emerging Computer-Aided Systems Engineering (CASE) tools in an attempt to evaluate and assess the structure and functionality of the NCC.

2. PHASES OF THE RESEARCH PROJECT

Figure 1 was included in Progress Report 1¹ to portray the activities pursued by the SEDL on this project.

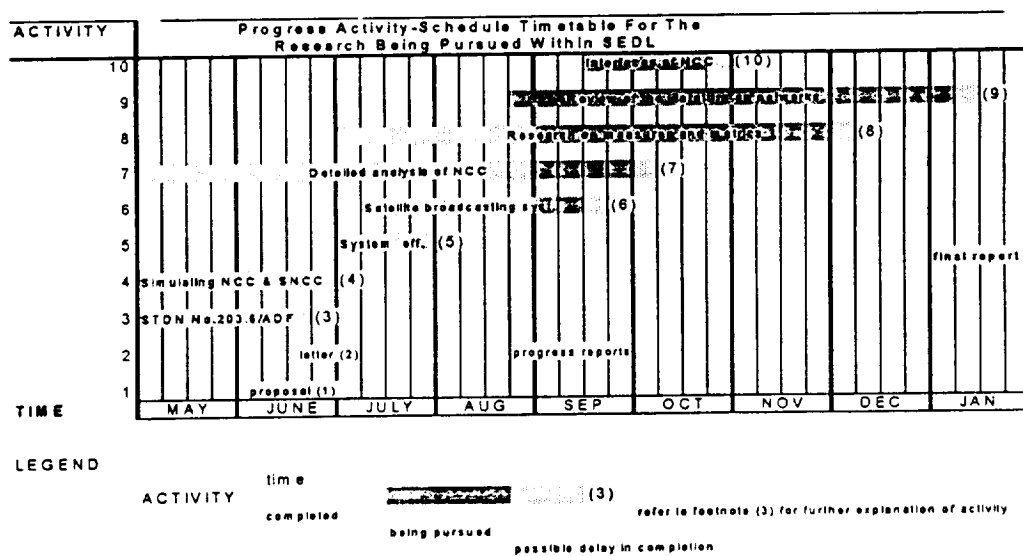


Figure 1. Project Activity Schedule

¹ Appendix A

During the first phase, focus was mainly on describing the functionality of the NCC through defining measures of systems effectiveness and their impact on cost. As a tool to aid in visualizing these two dimensions, the Decision Evaluation Display (DED) as seen in Figure 2, was depicted. While progress was made in defining performance measures of signal transmission in Satellite Telecommunication Systems², and in Network Systems control³, difficulty and lack of information impeded tracing of the cost dimension.

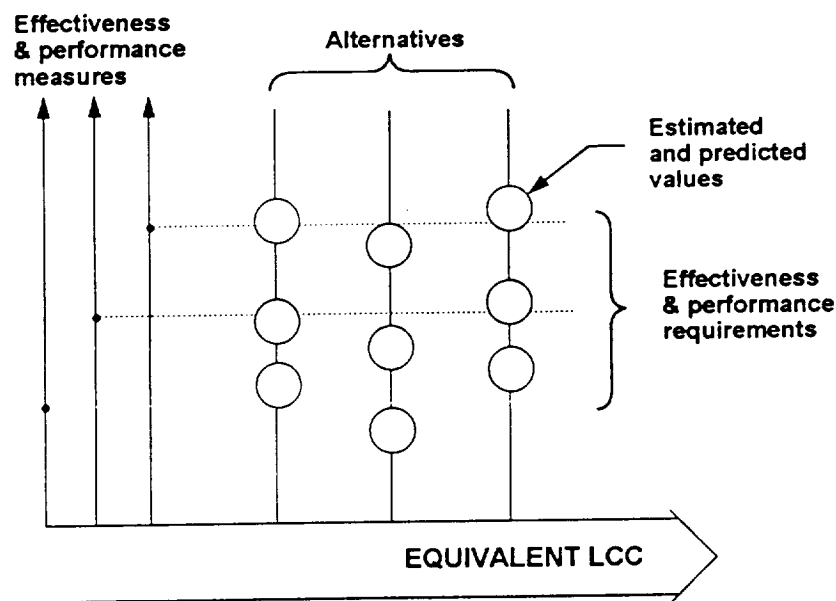


Figure 2. Decision Evaluation Display

²Appendix B

³Appendix C

A generous database of measures and metrics exists within SEDL. These were accumulated in the following reports between project start and 1994:

- (1) November 16, 1990. Progress Report.
- (2) December 28, 1990. Network Top Level Performance Criterion.
- (3) April 25, 1991. Space Network Scheduling Algorithm.
- (4) May 28, 1991. Modeling Approaches for Space Network Scheduling.
- (5) May 18, 1992. A Hypothetical Example to Demonstrate an Application of the Integrated Decision Approach.
- (6) July 2, 1993. A Summary Of Systems Effectiveness And Performance Measures.
- (7) September 30, 1993. Measures and Metrics of Satellite Telecommunication Systems Signal Relaying.
- (8) November 17, 1993. Measures And Metrics Of Telecommunication Networks Control.

3. CASE TOOLS: CORE AND RDD-100

The second phase of the project revealed the necessity of resorting to a comprehensive Computer-Aided Systems Engineering (CASE) tool to organize, summarize, and consolidate system elements, measures, and metrics within the NCC. For that purpose, CORE, an emerging CASE tool developed by VITECH Corporation, was used to link the earlier defined performance measures with the originating requirements of the NCC in an effort to fill the missing gap of cost allocation.

Figure 3 depicts a schema of the logic that prompted the use of CORE. The user of NASA references will note, while there is generous documentation of originating requirements, functions, items, and performance indices, there is difficulty in the traceability between entities, relationships, and attributes in a structural manner. CORE emphasizes requirements analysis and traceability management. It supports the conceptual and preliminary phases of design by defining the problem, analyzing the needs, performing feasibility analyses, defining operational requirements, and creating a maintenance concept. Furthermore, it can be used to analyze, organize, and re-engineer existing projects.

Several reasons lead to the choice of CORE from among other CASE tools. Other software are not available because they are proprietary, expensive, and/or require powerful workstations. CORE, on the other hand, is an inexpensive tool which runs on PC's in a Windows environment. It supports the requirements of the Systems Engineer in the primary phases of system definition, analysis, and design. Prior work with CASE tools lead to use of RDD-100 by Ascent Logic. The report dated November 16, 1990 gives essentials of the applicability of this CASE tool to NCC analysis.

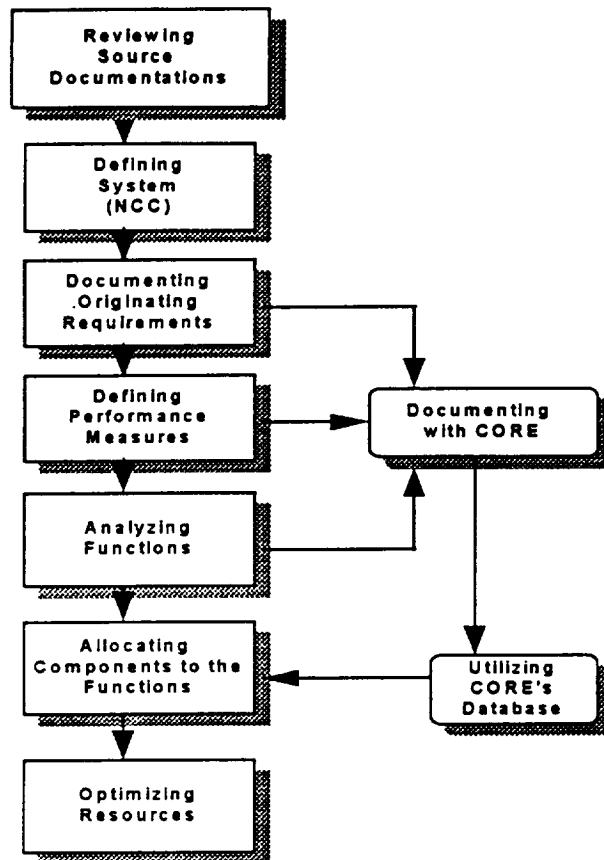


Figure 3. Systems Engineering Analysis and CORE.

4. AN EXAMPLE OF CORE's CAPABILITIES

The following example is provided to show how CORE may be utilized to analyze the NCC in a hierarchical fashion, beginning with requirements analysis and ending with physical architecture. All diagrams henceforth shown are print-outs from CORE.

4.1 Defining The User's Domain

The Systems Engineering process begins by the user first defining the domain in which he belongs. Figure 4 is a hierarchical structure that defines the domain of the NASA Satellite Tracking and Data Relay (TDRS) Network. It is built from several components including NCC, SN, GN, etc. Data in CORE are input in a menu-driven fashion. All element descriptions and details are summarized in the subsequent menus. As an example, Figure 5 shows the references that were used to extract the originating requirements of the NCC.

4.2 Hierarchical Traceability

A hierarchical traceability diagram of the requirements is seen in Figure 6. A black square on the upper left corner of a block (see Manage the STDN and Conduct Lead Center Activities) implies that it is expandable and contains more information. Figure 7 is a fully expanded diagram that decomposes the functions to be performed and the subsequent components from which they are built.

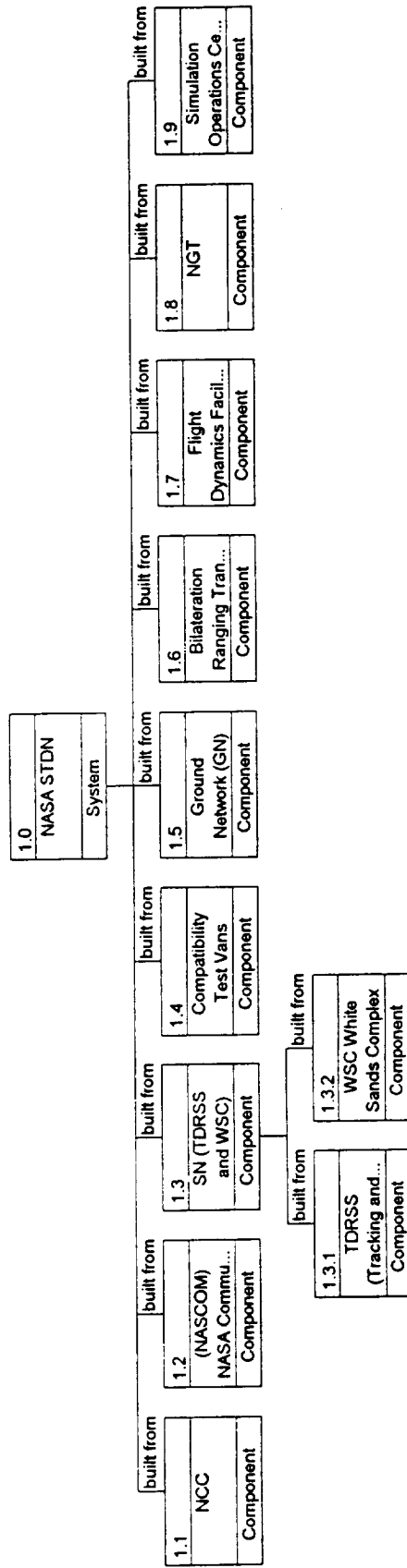


Figure 4. Components Comprizing the NASA STDN.

File		CORE		Edit	Target	Views
NCC References [Source]						
Name	NCC References					
Author	SEDL					
Creation Date	December 17, 1993					
Number	0.0					
Abbreviation						
Description	NCC references include: 1) STDN No. 203.6/NCC 2) STDN No. 203.13/NCCDS 3) STDN No. 106 4) SEDL Progress Report of November 16, 1990 5) Howard University Report "Simulating the NCC and the SNCC operations". 6) Howard University Progress Report dated July 31, 1991					
Source Type						
Modification Date	December 19, 1993					
Modification Time	3:26:01 PM					
causes	Originating Requirement 1.0 NCC Original Requirements					
documents						
generates						
owned by						
						Sort: 123

Figure 5. CORE Windows Menu Showing Documentation of References for the NCC.

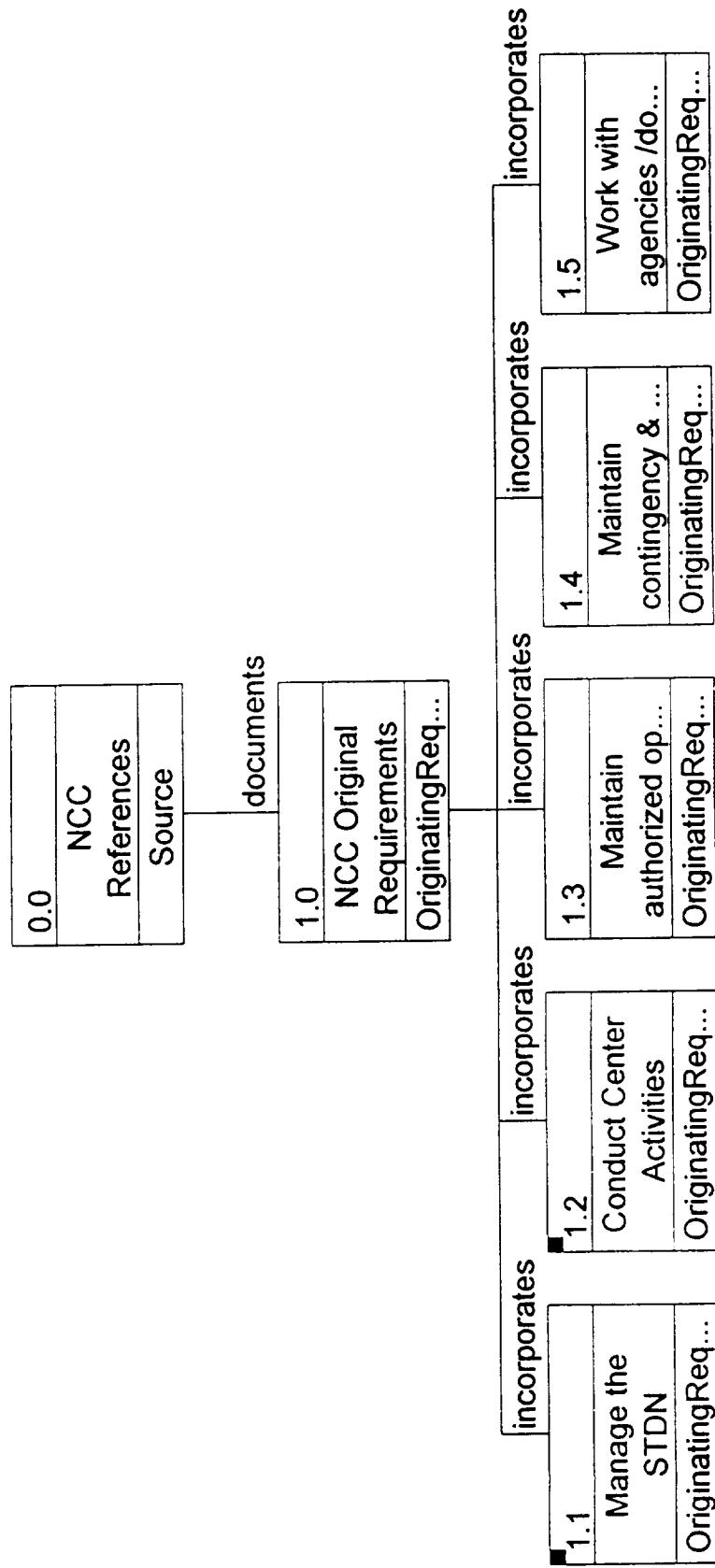


Figure 6. Hierarchical Traceability Diagram of NCC Originating Requirements.

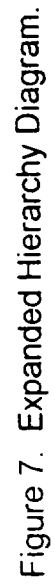


Figure 7. Expanded Hierarchy Diagram.

4.3 Documenting The Inputs

All blocks are described in detail using the *text* menu. Figure 8 shows the text menu of the function Resource Planning. A detailed description of Resource Planning is documented. Relationships such as *constrained by*, *decomposed by*, and *allocated to*, as well as others are also included in the input.

4.4 Linking Performance Requirements To Functions and Components

Once the entities and attributes that create the system are identified, Performance Indices that bound the behavior of the functions must be attached. Consider the example shown in Figure 9. The diagram is called an Entity Relationship (ER) diagram. This chart is used to summarize, in a visual format, all the relationships of a selected element.

A Systems Engineer may include as much detail in relationships as possible. Our interest lies in linking the constraints of the Performance Measures with the function of interest (Service Planning). We thus refer to Figure 10 which was developed by inputting the constraints in the same menu-driven fashion; a clear hierarchical traceability is thus possible whereby description and detail may be accessed by simply double-clicking on the desired element. Note how cost is traced in the diagram of Figure 10. This is a very important constraint that many designers overlook. Using a system design tool such as CORE enables the designer to account for this parameter for any element and at any location in the program.

1

Name	Resource Planning
Author	System Engineer
Creation Date	December 19, 1993
Number	1.1.3
Abbreviation	
Description	The NCC is responsible for the allocation of STDN resources and operational support. It provides user access to network resources by acting as the point of contact between users and the STDN. Users communicate their requirements (schedule requests, database inquiries, etc.) to the NCC which, in turn, generates appropriate scheduling and control messages to commit the necessary STDN resources to provide requested reports.
Duration	
Priority	
Modification Date	December 19, 1993
Modification Time	5:03:30 PM
<ul style="list-style-type: none"> → allocated to causes → constrained by → decomposed by decomposes documented by exhibits exits by generates 	Constraint Scheduling During Prime Shift Period
Sort: 123	

Figure 8. Text Menu of Resource Planning Highlighting the Constraint Relationship.

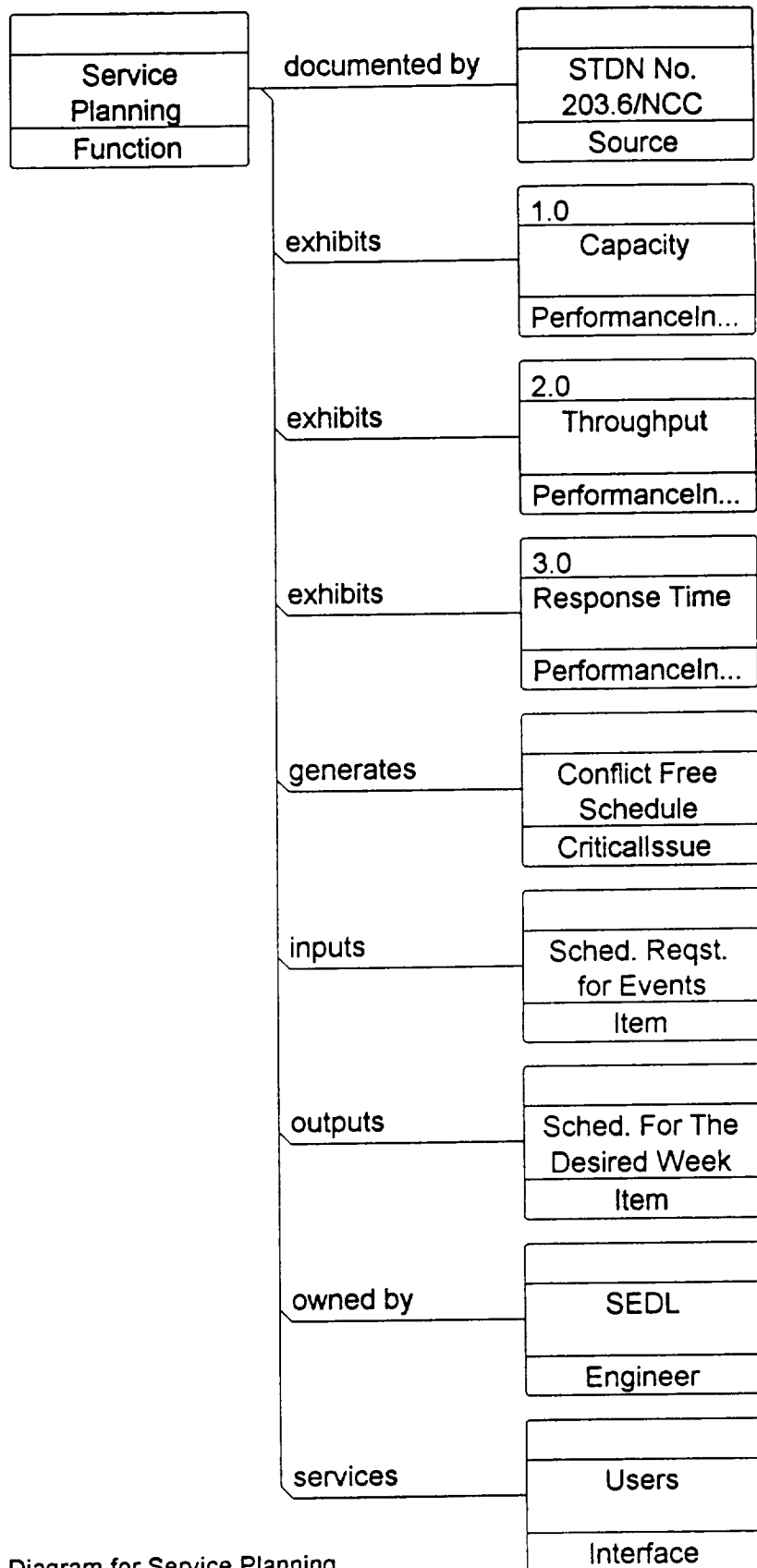


Figure 9. ER Diagram for Service Planning

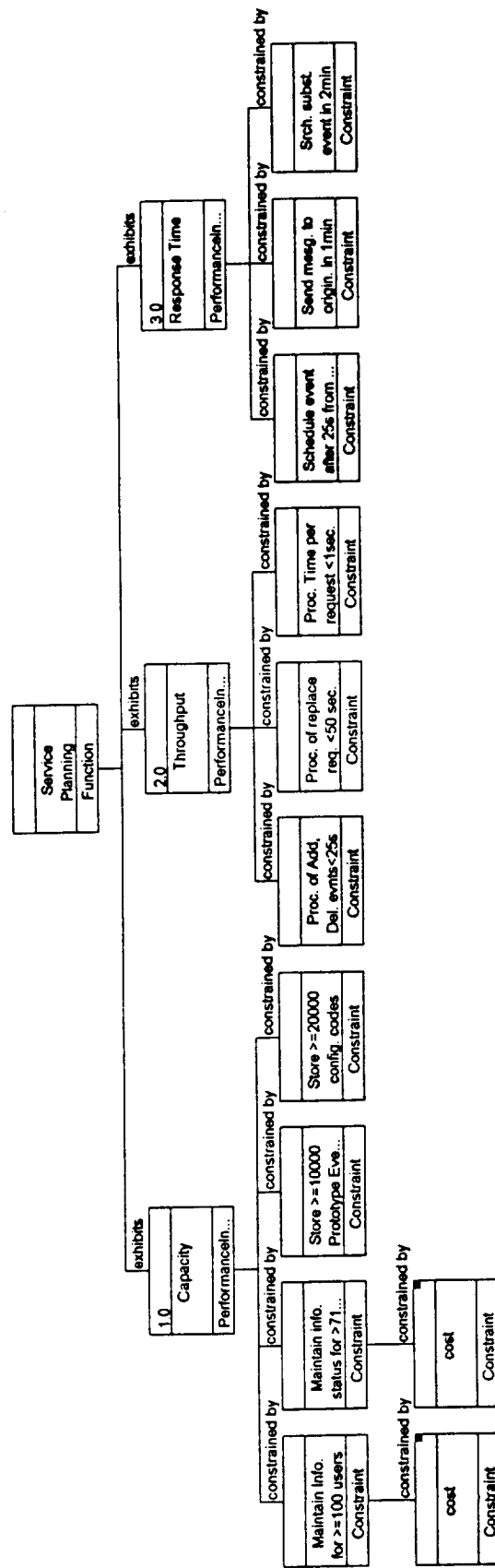


Figure 10. Hierarchical Decomposition of Performance Indices for Resource Planning.

5. CONCLUDING REMARKS

This research project has again come to the conclusion that a top level Systems Engineering tool helps the designer to organize, summarize, and consolidate measures and metrics and then link them in a database management shell to the functional requirements of the system. By using CORE, we were able to demonstrate an example of creating a traceability database that included metrics and cost aspects in the analysis and documentation of the Network Control Center.

Candidate alternatives may be compared based on the dimensions of effectiveness and cost, by using earlier mentioned tools such as the DED. Furthermore, since the database is quite detailed and easy to retrieve, the task of simulation modeling of the existing system may be carried out in a more accurate manner.

While we were bound by the short span of time for this research, this project has given us insight as to the practical applicability of CASE tools in system modeling and architecture. We strongly recommend that the direction of this research be continued further. SEDL at Virginia Tech is an appropriate resource for investigation along these lines.

APPENDIX A

I. INTRODUCTION

This report contains a progress activity- schedule timetable (see p. 4) for the research on Systems Engineering Technology for Networks being pursued within the Virginia Tech Systems Engineering Design Laboratory (SEDL). Activities beyond August 1993 are the most likely to be pursued however, any activity may be altered if we believe it is for the benefit of the research. Activity progress is translated in a graphical manner by difference in shading. The legend of the figure further expands on this issue. An elaborate explanation of each activity is also included in Section IV.

We will welcome any suggestions regarding the present activities that will lead to further assistance to Howard University in this project.

II. MEMORANDUM OF PREVIOUS DOCUMENTS

Researchers at SEDL have submitted the following documents as of August 31, 1993:

1) A proposal titled "Planned Research on Systems Engineering Technology for Networks". A description of the objectives and methodologies for the proposed research were henceforth stated. Feedback has not yet been received with regard to the planned research.

2) A letter to Dr. Tepper Gill from Dr. Wolter Fabrycky dated June 22, 1993 requesting updated versions of the following documents:

- STDN No. 203.6/NCC
Functional and Performance Requirements For The Network Control Center-
February 1986
- STDN No. 203.13/NCCDS
Data System (NCCDS) Network Control Center Detailed Requirements-
Revision 3 - November 1989
- Network Control Center - Block II
Project History Report - April 1990
- STDN No. 203.13/NCCWS
Network Control Center Workstation Requirement-
Revision 1 - March 1988

IV. ACTIVITY DESCRIPTION

The following is an elaboration on the activities that have either been completed or are being pursued. Others are planned during the project duration.

(1) Proposal.

Submitted on June 22, 1993. Contains a description and methodology of the planned research.

(2) Letter.

Dated June 22, 1993 requesting updated NASA documents.

(3) STDN 203.6/ADF.

Thorough review of the document titled "Functional and Performance Requirements for the Acquisition Data Function (ADF)- September 1983".

No report was submitted for this activity.

(4) Simulating NCC and SNCC.

Review of the research pursued by Howard University.

No report was submitted for this activity.

(5) Systems Effectiveness and Performance Measures.

Thorough research on the measures most often used by designers of systems. The objective is to document and define Systems Effectiveness and Performance Measures that influence the phases of the life cycle of any system.

No report was submitted for this activity.

(6) Satellite Broadcasting Systems, Planning and Design.

Review of the book written by J.N. Slater and L.A. Trinogga to understand the nature of network systems design.

Activity being pursued.

(7) Detailed Analysis of NCC.

Includes a review of documents in the possession of SEDL including NASA documents and Virginia Tech previous research reports.

Activity being pursued.

(8) Research on measures and metrics.

Review of literature related to systems design in an effort to create a global understanding of measures and metrics that are widely accepted and used.

Activity being pursued.

(9) Review of the literature on networks.

Search in journal articles on state-of-the-art network design and requirements.

Activity being pursued.

(10) Interfaces of NCC.

Review of the requirements for the proper operation of the Network Control Center with its various interfaces.

Activity has not yet proceeded.

APPENDIX B

INTRODUCTION

The following progress report summarizes the research pursued during the month of September. The focus of the research was to define measures and metrics of Telecommunication (Telecom) and Satellite Telecom systems that affect the cost of signal relaying.

PERFORMANCE OF TELECOMMUNICATION SYSTEMS

Emphasis in this report is mainly on the basics of signal transmitting and receiving from a hardware point of view. Understanding these basics is a stepping stone toward understanding general communication and telecommunication (Telecom) networks system capabilities, requirements and constraints. Several metrics related to performance measures, decision variables, and parameters have been defined. These will prove useful when simulating the information traffic flow in the NASA Network Control Center. The reader is referred to the Table at the end of the report for a summary of these metrics.

TELECOMMUNICATION SYSTEMS BASICS

Figure 1 on the following page is a summary of Telecom system architecture, capabilities, requirements, and constraints. We will discuss these topics in detail in the following sections.

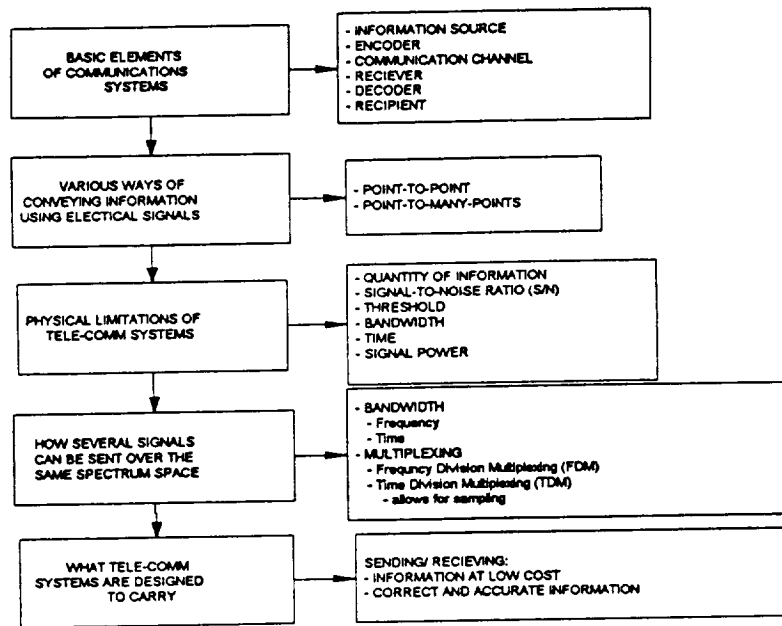


Figure 1. Elements, requirements, and capabilities of telecommunication systems.

ELEMENTS

Elements of a Telecom system are shown in the schematic diagram below.



Proper function of each element, in other words, availability and reliability, depends on the performance of the electronic hardware that configures them.

MEANS OF CONVEYING INFORMATION

Point-to-point systems are a natural part of Telecom networks. Typically, central switching is the only economic means for n -way communications. With n users, each would need $n-1$ switches to connect one with the others; thus a total number of $n*(n-1)$ switches would be required if no central switching method is used.

The cost of such a scenario becomes prohibitively expensive as n increases. Central switching thus saves on the following two parameters:

- (1) *Quantity of wiring and cabling.*
- (2) *Number of switches used.*

The variable to account for is the capacity of Bandwidth (to be explained) that a wire can hold. For example, a fiber optic cable has an unlimited Bandwidth and essentially noiseless transmission thus offering much higher performance than a copper cable.

While point-to-point is a structure of the communication network system at an operational level, we also account for the case of the point-to-many-points connection typically during broadcasting and satellite relaying. Proper function of point-to-many-point systems depends on the availability and reliability of the elements discussed in the schematic diagram on page 3.

PHYSICAL LIMITATIONS

Limitations of information systems depends on two important metrics namely, *Bandwidth and signal-to-noise ratio*. We stress on the term metric due to the fact that the above mentioned are considered as performance measures if it is in the interest of the designer to detect the quality of information sent; they may also play a role as design dependent parameters when the designer considers them as an inherent characteristic of the system he is designing.

Bandwidth is the difference in cycles per second (Hertz-Hz) between the highest and lowest frequencies in a signal to be transmitted. Also defined as the width of an electronic transmission path or circuit in terms of the range of frequencies it can pass.

Bandwidth is an extremely important characteristic which will be repeatedly emphasized because the cost of *signal transmission* (a performance measure)

depends fundamentally on the Bandwidth. Higher Bandwidth signals cost more to transmit because the equipment costs more.

Since Bandwidth has units of cycles per time (Hz), thus in order to double the amount of information or send the same amount twice as fast, we double the frequency range or Bandwidth. *Speed of information* transmission is thus a performance measure.

Signal-to-noise (decibels-dB) ratio reflects the ratio of the signal power to the noise power, thus indicating a measure of how distorted the information has been received. It follows a logarithmic scale. A high ratio indicates a high quality of information reception in other words undistorted information at the receiving end.

Other parameters that create physical limitations are:

- *Threshold*: the level at which an undistorted signal can be detected. It depends on the sensitivity of the receiving equipment and the magnitude of the noisy fluctuations which always occur in any communications channel due to electric noise in the atmosphere.
- *Quantity of information*: capacity of Telecom elements to carry Mega bits per second of information (Mbs).

To summarize, It is evident that transmission of information requires the effective allocation of both time and frequency, put in different words the allocation of bandwidth and time. When the signal power exceeds a certain threshold, it can be detected at the receiving end. Depending further on the signal power, a signal-to-noise ratio establishes the quality of the signal received.

MULTIPLE SIGNALS ON ONE SPECTRUM

Sending several signals on one spectrum during a period of time increases the efficiency of the system and reduces cost. Optimizing the *number of transmission systems for each channel capacity*, a design variable, is possible through multiplexing. As previously indicated, while the quantity of information transmitted depends on Bandwidth and time, two methods exist for multiplexing:

- Frequency Division Multiplexing (FDM): Divides the bandwidth, where each signal takes up a certain Bandwidth from the spectrum during the entire time of transmission.
- Time Division Multiplexing (TDM): Divides the time, thus uses times sporadically using up small portions of the time with a signal or many signals. The importance of TDM is that signals can be mixed in a time period by separating them in time, as long as one can keep track of which signal is being sent and when in order to reconstruct the messages.

TDM is an effective utilizer of Bandwidth and thus a cost effective technique. It promises low cost transmission of information. However, in order to send analog signals via TDM, requires that portions of the signal be sent without in anyway distorting the meaning of the information. This requires a process known as *Sampling*. Accurate sampling of the transmitted signal without destroying the original signal requires:

- Determining the *sampling rate* (a design variable) in units of pulses per second needed in order to represent the signal accurately.
- Have high performance equipment.
- Have facilities that can capture accurately the original signal in order to interpret the information.

A design criterion is that sampling rate is at least twice the highest frequency in the information signal itself.

TELECOMMUNICATION SYSTEMS PERFORMANCE

It should be clear that the focus of the designer of Telecom systems should primarily focus on (1) reducing the *cost of sending an amount of information* and (2) ensuring that the information relayed is accurately received. The designer should also be concerned with the effective utilization of the channel capacity through the effective allocation of time, Bandwidth, signal strength, signal power, and noise. Figure 2 shows an economic tradeoff between cost and technology capability when looking at the cost of sending information with respect to the parameters of Bandwidth (quantity) and signal-to-noise ratio (distortion).

Figure 3 shows the parameters, variables, and performance measures in a cause and effect correlation scenario using a fish-bone diagram; while the table at the end of the report gives a summary of these metrics.

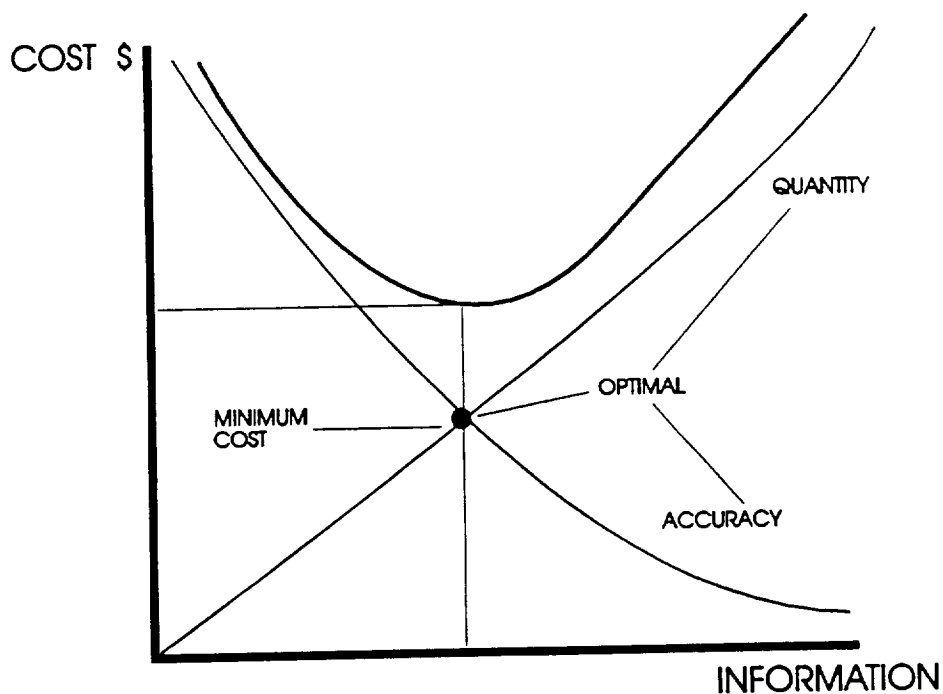


Figure 2. Cost of transmission of Information.

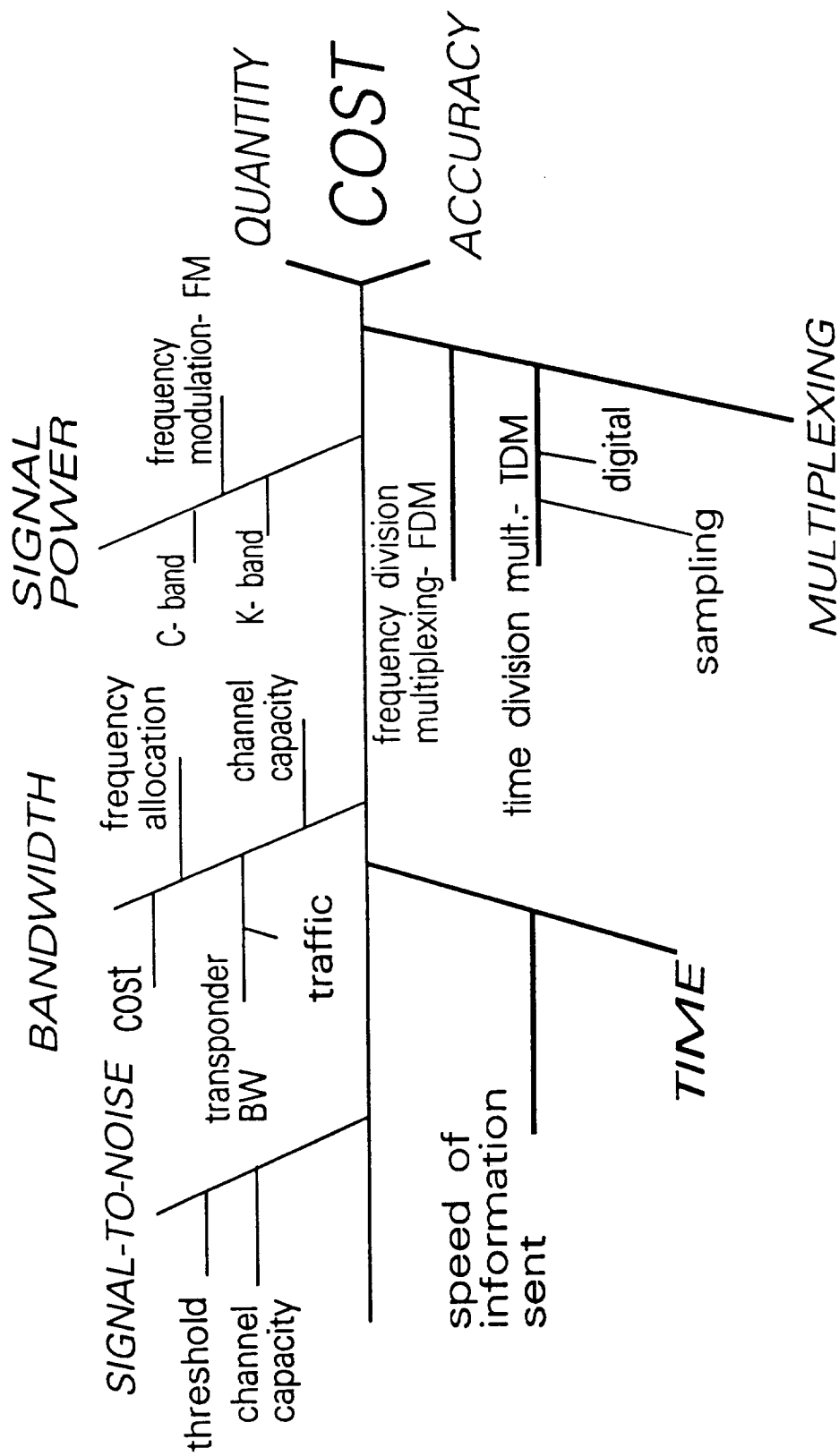
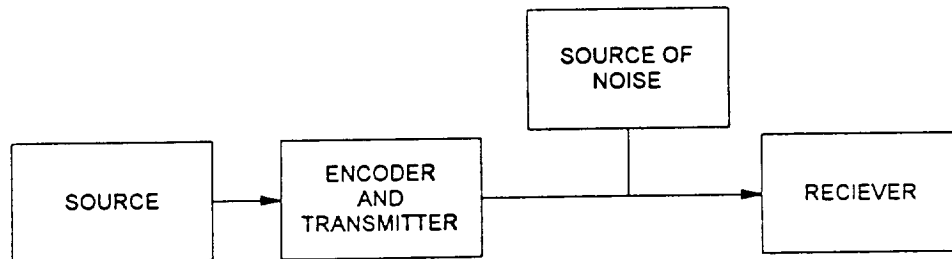


Figure 3. Performance measures, parameters, and variables

SATELLITE TELECOMMUNICATION SYSTEMS

Satellite Telecom systems follow the Shannon- Weaver linear communication models consisting of the following elements:



The space segment acts as the receiver/ transmitter, the earth segment as the source of noise/ receiver/ transmitter, and the communication channel as the source of noise.

We are particularly interested in the earth segment since it is the Network Control Center.

The primary element of a satellite is the transponder, a highly complicated electronic device that receives a signal from one source, amplifies it and transmits it to a second source without the loss of any information. Operating frequencies of the transponder are referred to as either the C- band (4-6 GHz) or the K- band (12-16 GHz). Transponder Bandwidth depends on the amount of traffic the sender desires to transmit. We thus have a performance measure to be taken into consideration, the *transponder Bandwidth*.

The life cycle of a transmitted signal is summarized as follows:

- Signals- in the form of computer data, video, voice- are sent to the transmitter.
- Signals in the transmitter are processed to accommodate as many users as possible.
- Processed signals are transferred to a high power amplifier.
- Signals are transmitted to the satellite transponder.

Accommodating many users can be evaluated through the ability of multiplexing- the *number of signals per channel*. We may therefore consider it to be a performance measure.

TRANSMISSION AND RECEIVER DESIGN TRADEOFFS

Typically there is loss between the earth segment and the satellite segment due to noise. Signal power is reduced by factors of as high as 1 million. Thus we must have either powerful transmission or powerful reception in order to capture an accurate message. A design tradeoff plays a role. The designer must choose between the gain or amplification of the transmitter, transponder on board the vehicle, or the receiving station. Less power in the transmission means investing in more costly receivers, typically having larger antennae. Since the number of receivers exceed the number of transmitters, it would be more cost effective to invest in high power transmission both in the vehicle and on the ground.

An important variable therefore is the *signal power* from the receiver and transmitter. The performance measure that is directly affected is the signal-to-noise ratio or the accuracy of the information relayed.

A second performance measure is the quantity of information in Mbs that is relayed through an effective utilization of the Bandwidth leading to a more efficient utilization of the communication system at a lower cost.

Table. Measures and Metrics

METRIC	PERFORMANCE MEASURE	PARAMETER	VARIABLE	UNITS
Cost of signal transmission	X			dollars
Bandwidth (BW)	X	X		Hz
Signal-to-noise ratio (SN)	X	X		SN
Quantity of information relayed		X		Mbs
Time	X	X		seconds
signals per channel			X	sig/channel
Transponder Bandwidth		X		Hz
Multiplexing	X			quantity
Signal power (receive/transmit)			X	Watts
Sampling rate			X	pulses/s
Threshold		X		Pulse
Quantity of wires and cables		X		linear ft.
Number of switches		X		quantity
Capacity of cable (BW)			X	Hz- Mbs

APPENDIX C

INTRODUCTION

The prior September Progress Report referenced *SEDL HU/pr2/09.30* defined some general performance measures, parameters, and variables related to the hardware of signal transmission. Our aim through this document is to research the measures and metrics that describe traffic flow, identify the most common approaches in network systems analysis, and further define the role of network systems control.

INFORMATION TRAFFIC FLOW

Proper network systems design requires a comprehensive consideration of: (1) traffic entities flowing within the network, (2) traffic flow patterns between users, (4) providing the users with a desired Grade Of Service (GOS) when they input their messages, (5) providing a desired Quality Of Service (QOS), and (6) accounting for techniques used to control network flows and performance.

Information Traffic Parameters

Input traffic may be characterized by:

1. Message/Call arrival Rate (λ). A measure of the frequency of messages/calls that are arriving to any node of a network during a unit of time usually a second. For a large number of users, the arrival rate is represented by the negative exponential distribution.
2. Message Length or Call Holding Time (TH). The length of an entire message string is generally measured in terms of discrete traffic units. The call duration is measured in terms of the occupancy of the associated link. The call arrival rates and their duration determine the sizing of the transmission links. Message lengths and call duration are represented by various probability distributions.

3. Traffic Intensity (A-Erlangs). A measure of total traffic being handled at any given time by the entire system or any of its subsystems.

$$A = \lambda * TH \text{ erlangs}$$

When a subsystem consists of a single resource, for example, a link or Central Processing Unit or disk file, the traffic intensity in that resource cannot exceed 1 erlang. In practice, most individual resources do not experience traffic loads exceeding 0.7 or 0.8 erlangs. The resource load is represented by:

$$\rho = \lambda * TH$$

Performance Measures

A list of Performance Measures whereby proper system evaluation may be pursued, may vary in definition and quantity. However, there seems to be accepted attributes which satisfy user requirements when choosing yardsticks for network systems evaluation. In general, performance measures may be grouped into seven classes:

1. Cost: the backbone of any Network System. Consists of:
 - Cost of nodal hardware, cost of sites and maintenance.
 - Cost of lower level iterative models of network service nodes. Example: cost-per-bit data.
2. Throughput: the total amount of traffic handled by a system in a fixed time period.
 - Maximum Number of arriving messages (calls) that can be handled during an average second of a busy hour (For Central Switching Systems - CS).
 - Max Number of calls that are being handled at present within the system during a busy hour (CS).

2. Throughput (cont.)

- Max number of input packets or messages that can be handled during an average second of a peak hour (Packet Switching- PS, Message Switching- MS, Distributed Data Processing- DDP, Distributed-Data-Base- Management- DDBM).
- Max number of transactions that can be handled by all the Data Processing and DBM nodes in the network during an average second of a peak hour (DDP, PS, MS, DDBM networks).
- Max number of sessions that can be handled by the system during a peak hour (PS, MS, DDP, DDBM).

3. Temporal attributes.

- Requirements related to response times and delays.

4. Storage capacity.

- Requirements related to storing a message for a significant amount of time.

5. Connectivity of the network.

- Total system connectivity is determined by the type of switch module used in networks and the number of network nodes employed in the system (CS sys.).
- Connectivity is a function of the number of subscriber links and the number of user nodes serviced by each subscriber link (PS, MS systems).

6. Quality of Service (QOS).

Effects from distortion- for CS systems using analog transmission techniques for voice applications:

- Specified as percentage of transmitted power lost with regard to protection against crosstalk in analog systems.
- Specified by the tolerated differences in Hertz (Hz) with regard to distortion caused by frequency shift resulting from differences in the carrier generators.
- In terms of protection against echo distortion and loss, QOS is specified in terms of (1) transmission loss and via net loss (VNL) plans adopted for each type of network link and path, and (2) availability of echo suppressors and their dynamic ranges.

6. Quality of Service (cont.)

Effects from Noise:

- Specification of Bit Error Rate (BER) and Mean-Time Between-Error Bursts (MTBEB) to account for the effects of noise.

Effects of Random Component Failure

- Mean Time Between (MTB) major failures (MTBMF) of the entire network caused by one or more malfunctions in the system.
- MTB nodal failures (MTBNF) of any one network node caused by one or more hardware or software malfunctions within the node.
- MTB nodal subsystem failures (MTBSF) of any one nodal subsystem causing a loss of service some users.
- To access the above mentioned Mean Time Between Failure's (MTBF) should be specified along with the average duration of each failure in order to access the QOS.

7. *Grade of Service (GOS)- Temporal Attributes.*

No accurate data on measures used by CS, MS, PS, DDP, and DDBM systems. However, The following are examples of measures used in subsequent systems:

- Statistical distribution of system response time- difference between time the user goes off-hook and moment the user is invited to dial the address digits (CS systems).
- Distribution of switching time spent per packet inside each type of PS node. PS time is the elapsed time between the moment the last bit of the packet is received and the moment the first bit of the same packet is transmitted toward the destination node on a network trunk (PS systems).
- Mean and 90 percentile of the MS time- the moment of receiving the last character in the MS node and the moment of transmission of the first character of the same message on the output link toward the destination user terminal (MS systems).
- Mean and 90 percentile values of the system response time- the time elapsed between the moment the last character of the input request is transmitted and the moment the first character of the output is received by the user (DDP and DDBM systems).

TECHNIQUES FOR INFORMATION TRAFFIC FLOW ANALYSIS

A useful tool for the analysis of network systems performance is the *Queuing Theory*, best described as the random behavior of queue processes of information units within a node in the network. The analogy of the flow of information units in Network Systems and queue processes is best described as follows. Information units that require a specific service are generated over time by an input source. These units enter the queuing system and join a queue. According to rules known as service mechanisms, these units are selected at certain intervals of time to be served. The service required is performed by the service mechanism. At the termination of service, the server releases the unit and the unit departs from the system.

Queuing Theory Fundamentals

This section is meant to acquaint the reader and highlight the most important parameters and performance measures of the Queuing Theory. It is by no means a comprehensive review of the subject.

A simple Queuing process consists of the following:

- Input Source. Two characteristics prevail. The first is the total population size of information units requiring service, for example, in CS systems it might mean the number of subscribers. The second characteristics deals with the distribution function that defines the arrival of information units to the queuing system. The most common assumption is that the number of units generated until any specific unit of time is Poisson distributed. This is also analogous to the assumption that the interarrival time is Exponentially distributed.
- Queue. Characterized by the maximum number of information units that can be stored in the queue (length of the queue).

- Service Discipline. Defines the order by which the units are chosen for service. Most common orders schemes are:
 - FIFO: First-In-First-Out.
 - LIFO: Last-In-First-Out.
 - Random scheme.
 - Priority scheme.
- Service Mechanism. Most important attribute is to find the time spent by each server while processing the unit. This is known as the Service Time, best defined by the Erlangian Distribution or one of its special cases, the Exponential distribution. In some cases, a constant service time is also used.

Performance attributes of a Queuing system are:

- $P(n)$. The probability that n units are in the queuing system (either being served or waiting to be serviced).
- L . The expected number of units in the system.
- $L(q)$. The expected queue length. Only those units waiting in the queue.
- W . Expected waiting time of each unit in the system. Also referred to as the Transient Time.
- $W(q)$. Expected waiting time of each unit in the queue excluding service time.

Fundamentals of Network Analysis

The properties of existing networks that are generally of interest in analysis are:

1. connectivity.
2. traffic flows.
3. network capacity.

1. NETWORK CONNECTIVITY

The connectivity of an n -node network can best be represented in terms of a connection matrix, $C(n)$ where $c(i, j)$ is either a 1 (direct connection between node i and node j) or a 0 (no connection). A measure of network connectivity is defined as:

$$K = \sum_{i=1}^n \sum_{j=1}^n c(i, j) \leq n^2$$

2. NETWORK FLOWS

Prior to studying network flows, the concept of the path that the call or transaction follows between node i and node j needs to be introduced. This path can be represented by a directed vector whose elements are the branches that are encountered on the way. A path is illustrated as follows:

$$P(i, j) = (c(i, k), \dots, c(1, j))$$

The length of the path can be defined as the number of branches traversed on the way. Enumerating the paths between any two nodes is a useful analytical tool in computing the loads on all trunks of a network (links that connect the network centers among themselves). The following steps must be performed:

- Enumerate the path of length q or less between any two nodes.
 - Obtain a connection matrix consisting of directed branches.
 - Compute P(q), the path matrix whose elements represent all proper paths of length q, first by letting P(1) = C(n), second, use P(q) = (C(n)*P(q-1)) to get P(q). Third, reject all items as they appear, in which any subscript appears more than twice (to eliminate redundant paths and keep only the proper paths).
- Choose the best path upon certain criterion such as minimum path.
- Add the from-to traffic load on all the branches of the path (obtained from a 100% sampled call log of a system- data specifying which customer vehicle is connected to which network node in the case where the traffic logs record only the customer vehicles.
- Repeat these steps for all the pairs of network nodes.

3. NETWORK CAPACITY

The Capacity of a network, as previously defined, is the total number of transactions that can be sustained during an average second of a busy hour. It is directly related to the capacity of each node to handle traffic, the capacity of each trunk bundle connecting two nodes, and the path lengths followed by transactions.

For the case of a fully connected network, The capacity is represented as:

$$E = \sum_{i=1}^n E(i, i) + \sum_{i=1}^n E(i, j)$$

CONCLUDING REMARKS

Smooth functioning of the network is impossible without *Network Control*. The role of Network Control may be summarized as follows: (1) It provides for dynamic traffic routing to avoid congestion and failed network resources, (2) provides fault monitoring, (3) fault isolation, (4) nodal/network recovery, (5) traffic protection, and (6) reporting all operational events. The function of The NASA Network Control Center is closely tied with performing the above mentioned activities.

This report illustrated typical tools for network analysis. Although much of the research involved in this report centered around public network systems, these concepts are useful as a first step toward understand the Network Control Center system, as it can be described as a combination of several of these systems.

At present, the progress is toward tying the system components requirements and the performance measures researched, using the CORE software (VITECH release 1.1).

ACRONYM LIST

- A: Traffic intensity in units of Erlangs.
- CS: Central switching systems.
- BER: Bit error rate.
- DBM: Data base management.
- DDP: Distributed data base.
- DDBM: Distributed data base management.
- GOS: Grade of service.
- λ : Message arrival rate.
- MS: Message switching.
- MTBEB: Mean time between error bursts.
- MTB: Mean time between.
- MTBMF: Mean time between major failures.
- MTBNF: Mean time between nodal failure.
- MTBSF: Mean time between nodal subsystem failure.
- MTBF: Mean time between failures.
- PS: packet switching.
- QOS: Quality of service.
- ρ : Resource load.
- TH: Message length or call holding time.